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Estimation of the Fishing Depth.

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By Akira Ochiai

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Mechanical Studies on the Trolling Gear I.
Estimation of the Fishing Depth.

By

Noboru Isouti and Tasae Kawakami*

With 2 Tables and 5 Textfigures

Introduction

In Japanese commercial fishery operating in coastal waters, trolling, often called jiging, is widely practical for many predacious species of fish such as dorphin fish, yellowtail, tunas, etc. In order that the hooks of a trolling gear may fish at any desired depth below the surface of water, two kinds of depressor have been traditionally used, namely lead sinker of gravity type and diving board of hydrofoil type. The hydrofoil depressor is widely in use on account of its simplicity especially for coastal fishery. There are several types with many variations both in shape and in construction, but many of the depressors used by Japanese fishermen have heen rather crudely constructed and improvised affairs. It is said that the construction and the regulation of its arrangement is delicate and severe in order to operate the gear satisfactorily.

N. Sato and I. Takayama[1] have devised an improved gear and carried out a series of tank experiments as well as of practical tests of operation in the open sea, but it seems to be somewhat complicated for practical use in commercial fishery of a small scale. After that, the hydrodynamic characteristics of hydrofoil depressors with some variations have been studied experimentally by H. Okuno.[2] As to the shape and tension of towing cable, we have a series of researches conducted by TMB of the Navy Department of U. S. A. There arise, however, some mechanical problems in practical operation.

The general arrangement of the trolling gear now in common use in Japan is shown in Figure 1 in some detail. By means of a fine leader or snood, one or

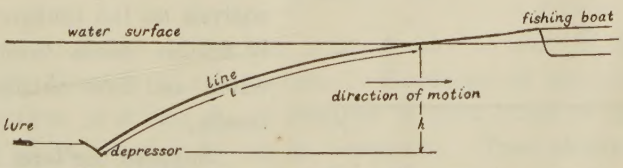


Fig. 1. General arrangement of the trolling gear in operation.

* Laboratory of Applied Physics

some lure jigs are connected to a rear point of the depressor. The forward edge of its under surface is fitted with a lead ballast of a suitable size to keep its stability during towing. The depressor is towed by a towline attached to a effective point on the upper surface usually without using any bridle. Two or more separate gears are operated by a trolling boat, either directly from the poop deck or by the use of trolling poles. Sometimes, the towline is weighted along its whole length with small spherical lead sinkers, which are of use not only for sinking the line but also for facilitating reeling in the line hand over hand. Usually the design of the gear has been merely a guess and its improvement has depended upon the extensive and practical experiences of every fisherman.

A problem that arises frequently in connection with the trolling experiments is that of estimating the depth at which the fish was caught. In this paper, a chart is presented which, for most frequent design of the gear, will help to reduce the labor of such calculations.

Theoretical Consideration

The solution of the problem introduced here may be reduced to make clear the shape of the trolling line in operation. In the treatment of the problem on the shape of the line moving so rapidly as in the case of trolling, it can be assumed that the weight of the line in water is negligible compared to the hydrodynamic force. Therefore the following assumptions are made, i. e. that the normal force acting on unit length of the line is given by $R\sin^2\theta$, where θ is the angle that the line makes with its direction of motion through the water, and R is the force acting on unit length of the line when it is normal to the stream, and that the tangential force acting on unit length is given by a constant F regardless of the angle θ. Based on these assumptions, L. LANDWEBER and M. H. PROTTER[3] have made a mechanical analysis on the configuration of perfectly flexible cable towing through the water, and have obtained the following results.

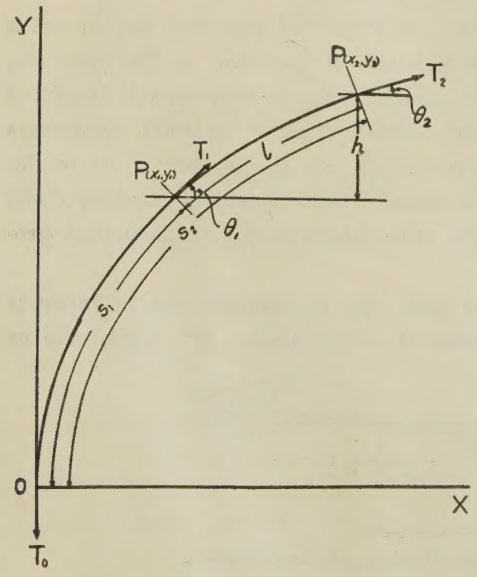


Fig. 2.

Suppose the form of a line towing through the water as shown in Figure 2, then choose a rectangular coordinates

(x, y) whose origin O is located at the point on the line where the line is normal to the direction of the motion. Let the x-axis be taken as positive towards the direction of motion and y-direction be directed vertically upward. Let s be the arc length along the line from the origin O to any point $P(x, y)$ on the line, T and T_0 be the tensions of the line at the points P and O respectively. The inclination angle of the line against the stream is measured counterclockwise from the direction of the stream. Then the solution of equilibrium equation is expressed by a non-dimentional parametric form as follows:

$$\frac{T}{T_0} = \tau(\theta), \tag{1}$$

$$\frac{R}{T_0} s = \sigma(\theta), \tag{2}$$

$$\frac{R}{T_0} x = \xi(\theta), \tag{3}$$

$$\frac{R}{T_0} y = \eta(\theta), \tag{4}$$

where τ, σ, ξ and η are transcendental functions of angle θ, whose numerical values have already been computed and tabulated for values of from 0 to 90 degrees in the case of $F/R=0.022$.

Now let us consider the practical problem of trolling gear. As shown in Figure 1, all parameters related to the point where the line is attached to the board and the point where the line intersects the water surface are distingished by subscriptions 1 and 2 respectively. Thus the problem is to find the depth h $(=y_2-y_1)$ of the board when the submerged length l $(=s_2-s_1)$ of the towline is given. From the equations given above, we have

$$\frac{R}{T_2} h = \frac{\eta(\theta_2)-\eta(\theta_1)}{\tau(\theta_2)}, \tag{5}$$

$$\frac{R}{T_2} l = \frac{\sigma(\theta_2)-\sigma(\theta_2)}{\tau(\theta_2)}, \tag{6}$$

$$\frac{h}{l} = \frac{\eta(\theta_2)-\eta(\theta_1)}{\sigma(\theta_2)-\sigma(\theta_1)}, \tag{7}$$

where R is expressed as

$$R = \frac{1}{2} C_D \rho U^2 D,$$

C_D being the drag coefficient of the line, ρ the density of fluid, U the speed of the motion and D the diameter of the towline. Equations (6) and (7) express Rl/T_2 and h/l as functions of θ_1 and θ_2, so that for a fixed value of θ_2 corresponding values of Rl/T_2 and h/l against θ_1 can be computed. Thus plotting the values of h/l against θ_2, contour curves for various values of Rl/T_2 as well as of θ_1 can be drawn. Figure 3 was obtained in this manner. This chart greatly facilitates the

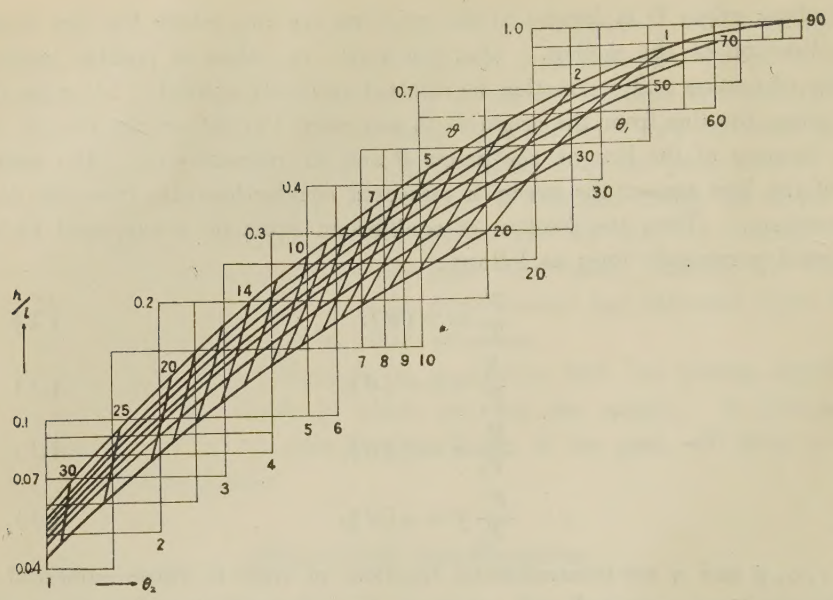


Fig. 3. Diagram for determining the working depth of a trolling depressor.

estimation of the working depth of a depressor.

Experiment and Results

The gear used in this experiment was arranged similarly as shown in Figure 1, except that a small protecting case in which two chemical tubes to indicate the fishing depth had been charged was attached to the snood in place of the hooks. The hydrofoil depressor was designed and made by one of the authors ISOUTI; it was a leaf shaped wodden plate slightly convexed upward with dimensions of 27.4 cm. in mid. length, 12.6 cm. in mid-width and 1.2 cm. in thickness. It is shown in Figure 4. A lead ballast of about 150 g. in weight was attached to the forward edge of the under surface of the depressor to keep balance during towing. The towline was medium-laid "Saran" cord with a diameter of 2 mm. Preliminary towing tests at sea showed that its behavior is satisfactory, the depressor assumed a stable attitude, in the working condition. Prior to the experiments, to determine the angle θ_1, the angle θ_2 was measured at an interval of one meter length of submerged towline. Thus the angle θ_1 was extraporated graphically to be 57 degrees which was virtually constant irrespective of the towing speed.

The field experiments were carried out in the Bay of Maizuru selecting calm day. The trolling gear was towed from the research boat Ryokuyô-Maru, whose speed was regulated as constantly as possible. The tension T_2 was measured by a ordinary

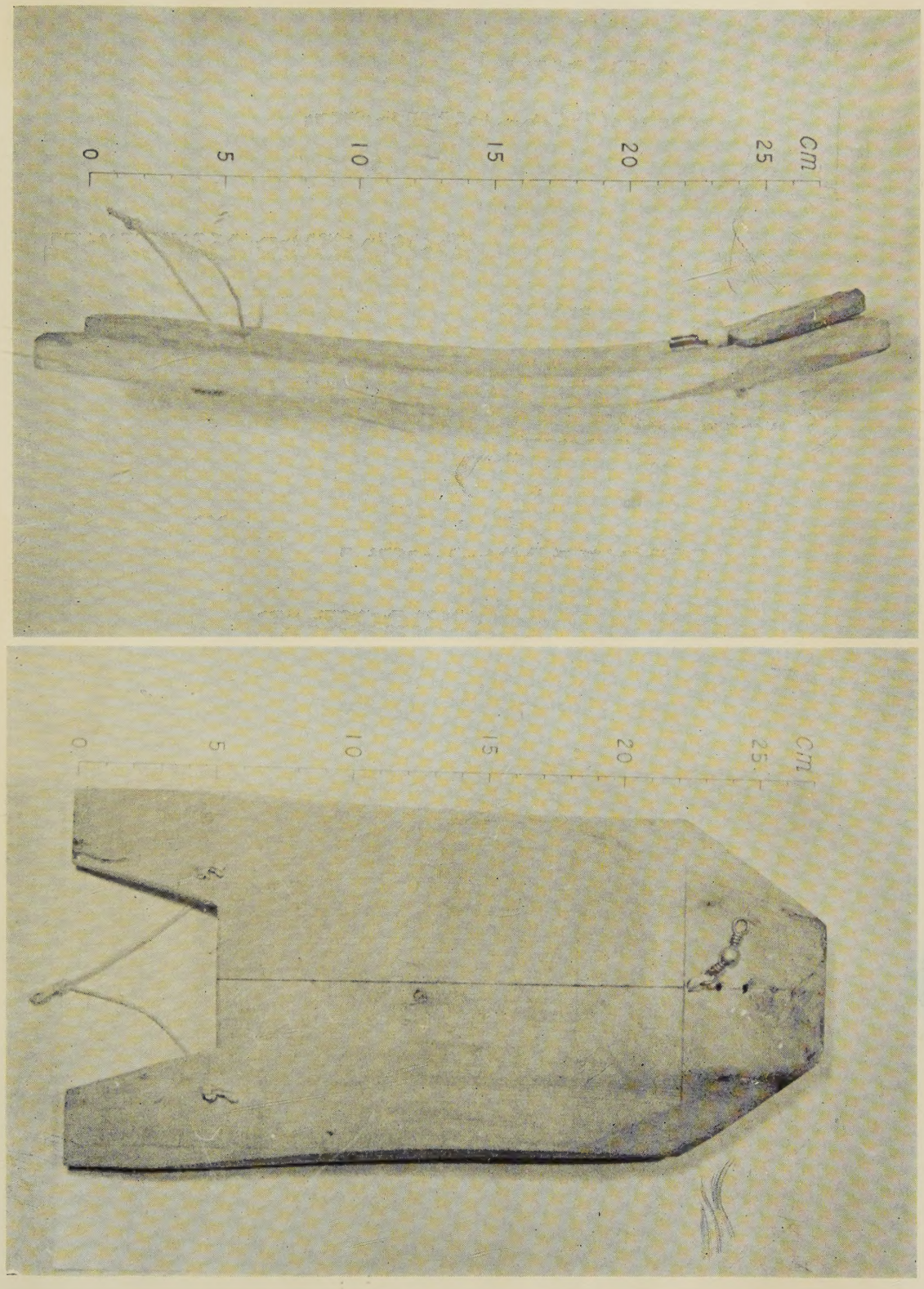
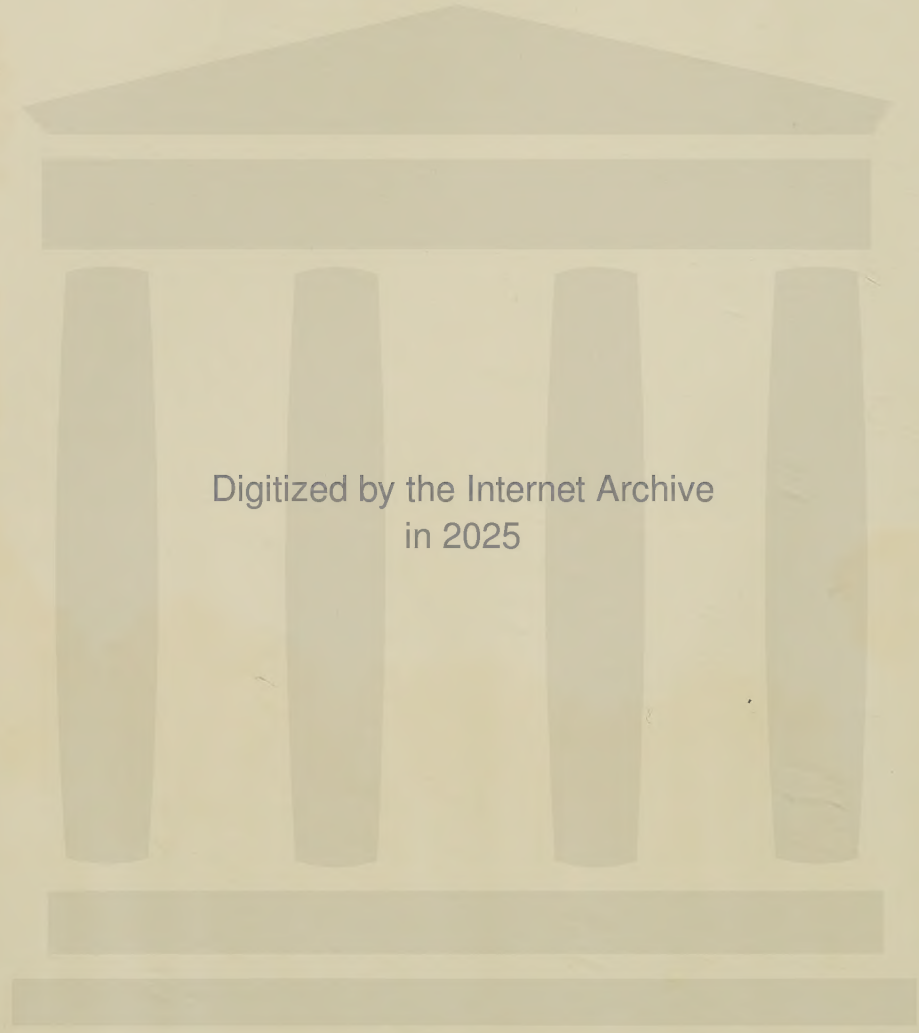


Fig. 14.



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spring balance and the angle θ_2 by a clinometer specially designed for this experiment. The length of the towline submerged in the water was varied from 5 m. to 20 m. The chemical tubes were recovered each time to know the actual working depth of the depressor. The results of observation were summarized in Table 1.

Table 1

No.	l (m)	θ_2(°)	T(kg)	U (cm/sec)	Rl (dyne)	h (m)
1	5	21.0	3.40	306	6.55×10^6	2.96
2	10	11.5	3.80	306	13.10 〃	4.47
3	15	7.3	4.25	318	21.10 〃	5.40
4	20	5.5	4.80	317	28.20 〃	6.30
5	9	12.2	3.90	305	11.40 〃	4.10
6	12	10.0	4.64	328	18.10 〃	5.00
7	16	7.0	4.62	306	20.95 〃	5.75
8	20	5.5	5.00	306	26.25 〃	6.90
9	5.5	20.5	4.33	306	7.20 〃	2.75
10	10	11.0	3.86	306	13.10 〃	4.87
11	17	7.0	4.60	328	25.70 〃	6.10
12	20	5.0	4.19	306	26.20 〃	6.30

The working depth of the depressor can be calculated from the submerged length, l, of the towline by determining the ratio h/l. If the value of R be given, this value can be read directly from Figure 3 by using any two values out of Rl/T_2, θ_1, and θ_2, that is the following combinations:

Method [1] Rl/T_2 and θ_2,
Method [2] Rl/T_2 and θ_1,
Method [3] θ_2 and θ_1.

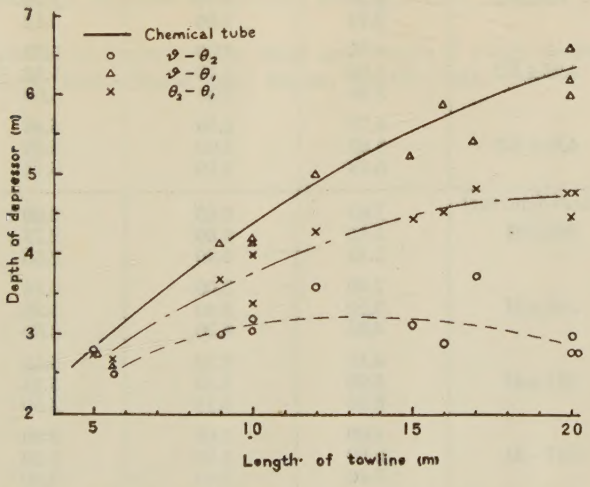

Fig. 5. Relation between the depth of depressor and the length of towline.

Among these, method [1] is a standard procedure because only the values obtainable on board are to be used. On the contrary, in the methods [2] and [3], some knowledges about the depressor are indispensable, but the method [3] is the only method in which the tension in the towline is needless.

In Figure 5, the depth of the depressor computed by these three methods and the actual depth estimated by the chemical tube are plotted against the submerged length of the towline. This figure indicates that the value obtained by the method [1] and [3] deviate systematically from the estimated value, whereas the method [2] shows a relatively good coincidence.

Table 2 ($Rl/T \equiv \vartheta$)

Length (m)	$\theta_2 \pm \Delta\theta_2$(°)	ϑ	$h \pm \Delta h$ [1] (m)	$h \pm h\Delta$ [2] (m)	$h \pm \Delta h$[3](m)
5	21.0±1.0	1.96	2.90 2.80 2.60	2.75	2.83 2.75 2.70
10	11.5±1.0	3.50	3.95 3.40 2.96	4.20	4.15 3.95 3.70
15	7.3±1.0	5.00	4.05 3.15 2.50	5.25	4.80 4.42 4.20
20	5.5±1.0	6.00	4.00 3.00 2.20	6.20	5.50 4.80 4.20
	TΔ±T (kg)				
5	3.4±0.2	1.85 1.96 2.09	2.70 2.80 2.90	2.83 2.75 2.65	2.75
10	3.8±0.2	3.34 3.50 3.70	3.15 3.40 3.60	4.25 4.20 4.15	3.95
15	4.25±0.2	4.83 5.00 5.30	3.00 3.15 3.30	5.32 5.25 5.00	4.42
20	4.8 ± 0.2	5.75 6.00 6.23	2.90 3.00 3.10	6.48 6.20 6.14	4.80
	U±ΔU(cm/sec)				
5	306±31	1.67 1.96 2.42	2.55 2.80 3.30	3.00 2.75 2.60	2.75
10	306±31	2.90 3.50 4.35	3.00 3.40 4.30	4.70 4.20 3.80	3.95
15	317±31	4.15 5.00 6.30	2.70 3.15 4.13	5.35 5.25 4.59	4.42
20	317−31	4.90 6.00 7.46	2.66 3.00 3.62	7.00 6.20 5.40	4.80

These facts may suggest that in addition to the instrumental imperfections and to the accidantal errors of measurement, there arises in the measurement of θ_2 a systematic deviation, which causes a disagreement in numerical estimation especially in the range of small θ_2. The reason is not clear under existing circumstances but these will be indicated obviously by the deviations, Δh, of estimation caused by a small variation of parameters; $\Delta \theta_2$, ΔT and ΔU. The results of this comparison are shown in Table 2, in which the variations in the parameters is chosen to equate with the range of technical errors in the measurement.

These deviations fall short of the actual errors and it seems to the authors that there are some room for discussion on the resistance law of the towline and further researches in this line is necessary. In any case, it may be recommended to use the method [2] for estimating the depth of the depressor.

Acknowledgment

The authors wish to express their hearty thanks to Mr. H. KURITA of the Kyoto Fisheries experimental Station for his good assistances to get the hydrofoil depressors and also to members of this laboratory for their assistance in carrying out the experiments. The expenses for executing this study were partly defrayed by the research fund from the Japanese Ministry of Education.

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Some Polyelectrolyte Properties of Sodium Alginate

By

Hiroshi Fujita, Akira Kishimoto and Kazuhiko Ninomiya*

Part I. Swelling of Sodium Alginate Gels in Concentrated Salt Solutions

Introduction

The swelling of polyelectrolyte gels (by polyelectrolyte is meant a linear high polymer molecule carrying ionizable groups on the chain) in electrolyte solutions has called attention of a number of investigators. More than thirty years ago Procter and Wilson attributed the swelling of gelatin gels in dilute acid solutions to the existence of Donnan equilibria between the gel and the surrounding liquid. Recently, Vermaas and Hermans[1] made an important improvement to Procter's classical theory by incorporating in it the modern expressions for the osmotic pressure of linear macromolecules and for the contractility of the gel network. They showed that the equilibrium volumes of cellulose xanthate gels swollen in various electrolyte solutions could be described satisfactorily in terms of their new theory. A more general theory of highly swollen polyelectrolyte gels in salt solutions has been presented by Katchalsky and Michaeli,[2] who introduced the electrostatic free energy contributed by the fixed charges on the polymer into the equation for the free energy of the gel network.

Sodium alginate, one of the typical of extracts from sea weeds, is a long chain molecules containing –COONa as ionizable groups. The major part of recent works on the interaction of swollen alginate gels and simple electrolytes has been concerned with ion-exchange capacities of this polyelectrolyte, and no quantitative description of the swelling properties has yet appeared in the literature. In the present paper, a brief description of Katchalsky's theory on the swelling of a linear polyelectrolyte in salt solutions is made, with particular interest in its limiting form for uni-univalent salt solutions of sufficiently high concentrations, and experimental data of equilibrium swelling and of Donnan distribution of simple ions on both sodium alginate and alginic acid in several concentrated salt solutions are interpreted in terms of the theory.

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Theoretical

Let us consider a volume V_0 of dry gel of a sodium alginate sample containing n_m monomeric units and n_{Na} sodium ions. The degree of ionization, α, of the gel is given by $\alpha = n_{Na}/n_m$. The monomeric units are arranged in chains, of Z monomeric units each, extending from one crosslink to the next. The crosslink herein referred to may be either a true chemical crosslinkage or an apparent one produced by entanglement of the polymer chains. When the gel is immersed in a salt solution, it swells to a volume V. At equilibrium, the chemical potentials of water and the salt in the gel phase are equal to those of respective species in the external solution phase. Thus, $\mu_w{}^{gel} = \mu_w{}^{ext}$ and $\mu_s{}^{gel} = \mu_s{}^{ext}$, where subscripts w and s denote water and salt, respectively. The second equation leads to the DONNAN equation for simple ion distribution, i.e.,

$$RT \ln (x_+{}^e x_-{}^e f_s{}^e) = RT \ln (x_+{}^g x_-{}^g f_s{}^g), \qquad \text{(I-1)}$$

where R is the gas constant, T is the absolute temperature of the system, x is the molar fraction of either cation or anion, and f is the mean activity coefficient of the salt either in the solution or in the gel phase; superscripts e and g denote the external solution and the gel, respectively. If f_s' s are assumed to be unity, Eq. (I-1) reduces to

$$RT \ln (x_+{}^e x_-{}^e) = RT \ln (x_+{}^g x_-{}^g). \qquad \text{(I-2)}$$

The molar fraction of i-th ion in the gel is represented by $x_i{}^g = n_i/n$, where $n = n_w + \sum n_i$, assuming the amount of polymer to be negligible as compared with those of free ions, $\sum n_i$, and of water, n_w, in the gel.

The chemical potentials of water in the external solution and in the gel phase are approximately represented by

$$\begin{aligned} \mu_w{}^{ext} &= \mu^\circ{}_w - RT\sum x_i{}^e + RT \ln f_w{}^e, \\ \mu_w{}^{gel} &= \mu^\circ{}_w - RT\sum x_i{}^g + RT \ln f_w{}^g, \end{aligned} \qquad \text{(I-3)}$$

where $\mu^\circ w$ is the chemical potential of water at a reference state, and f_w' s are the activity coefficients of water in the solution and in the gel. At equilibrium, there holds:

$$\Delta \ln f_w = \ln f_w{}^g - \ln f_w{}^e = -\sum x_i{}^e + \sum x_i{}^g, \qquad \text{(I-4)}$$

It is assumed that the difference in activity coefficient of water, $\Delta \ln f_w$, results only from the free energy of dilution of the polymer, F_{dil}. This means that the electrostatic free energy of the polyelectrolyte network is neglected. This neglect would be valid if the concentration of the external salt solution is sufficiently high as was the case treated in the present experimental work. Thus, one obtains

$$RT \Delta \ln f_w = \frac{\partial F_{dil}}{\partial n_w}. \qquad \text{(I-5)}$$

The expression for F_{all} may be obtained from the well-known FLORY-REHNER equation for neutral polymers[3], and introduction of it into Eq. (I–5) leads to

$$\Delta \ln f_w = \sum x_i^g - \sum x_i^e = \left(\frac{V_o}{V}\right)^2 \mu + \ln\left(1 - \frac{V_o}{V}\right) + \left(\frac{V_o}{V}\right) + n_p \left(\frac{V_w}{V}\right)\left(\frac{V}{V_o}\right)^{2/3}, \qquad \text{(I–6)}$$

where V_w is the partial molal volume of water and μ is the polymer-solvent interaction parameter. If the degree of swelling V/V_o is large enough, higher terms in the expansion of $\ln (1 - V_o/V)$ may be dropped, and one obtains

$$\Delta \ln f_w = \left(\mu - \frac{1}{2}\right) Q^{-2} + n_p \left(\frac{V_w}{V}\right) Q^{2/3}, \qquad \text{(I–7)}$$

where Q denotes V/V_o.

For convenience, let us consider the case in which a sodium alginate gel is allowed to swell in a uni-univalent electrolyte solution. Since in highly swollen gels, n is practically equal to n_w, the volume of the gel, V, is approximately given by nV_w. The volume of the dry gel, V_o, is obviously equal to $n_p Z V_m$, where V_m is the volume per monomeric unit in the dry gel and n_p is the number of chains involved in it. KATCHALSKY and MICHAELI[2] define a swelling ratio q by the relation:

$$q = n/n_p Z. \qquad \text{(I–8)}$$

It follows then that this ratio is related to the experimentally measured degree of swelling, Q, by the equation:

$$Q = q(V_m/V_w). \qquad \text{(I–9)}$$

If the number of free ions per monomeric unit in the swollen gel is denoted by p, the molar fractions of anion and cation in the gel phase, i. e., x_-^g and x_+^g, are represented by

$$x_-^g = (p - \alpha)/2q \quad \text{and} \quad x_+^g = (p + \alpha)/2q. \qquad \text{(I–10)}$$

Introduction of Eqs. (I–9) and (I–10) and of the numerical values of V_m for alginate and V_w ($V_m = 120\text{cm}^3./\text{mole}$, $V_w = 18\text{cm}^3./\text{mole}$) into Eqs. (I–2) and (I–7) yields

$$\ln x_-^e = (1/2) \ln (p^2 - \alpha^2)/4q^2 \qquad \text{(I–11)}$$

and

$$2 x_-^e = (P/q) - (\mu - 1/2)/45q^2 - 0.28/Zq^{1/3}, \qquad \text{(I–12)}$$

respectively. Equation (I–11) may be solved for p to give

$$p = 2 q x_-^e \left[1 + (\alpha^2/4q^2 (x_-^e)^2\right]^{1/2}, \qquad \text{(I–13)}$$

and for high enough salt concentrations the term $\alpha^2/4q^2 (x_-^e)^2$ is so small in com-

parison with unity that the above equation may be approximated by

$$p=2qx_{-}^{e}\left[1+\alpha^2/8q^2(x_{-}^{e})^2\right]. \qquad \text{(I–13)}$$

Substitution of this into Eq. (I–12) gives

$$q^{5/3}=159\ (1/2-\mu)\ Z+0.89\ \alpha^2 Z/x_{-}^{e}. \qquad \text{(I–14)}$$

This equation indicates that for a given degree of ionization the three-fifths power of the swelling ratio q increases linearly with the reciprocal of the molar fraction of anion in the external solution. It is shown that Eq. (I–14) is essentially the same as that obtained by VERMAAS and HERMANS[1]

When a polyvalent salt is present in the surrounding liquid, Eq. (I–14) is written in the form :

$$q^{5/3}=159\ (1/2-\mu)\ Z+1.78\ \alpha^2\ Z/\lambda\ x_{-}^{e}, \qquad \text{(I–15)}$$

where λ is the valency factor (see reference (1)).

Experimental

The sodium alginate used in the present work was furnished from Kamogawa Kako Co. through the courtesy of Professor T. Takahashi of the Institute for Industrial and Scientific Research, University of Tokyo. Of the material furnished two samples of different degrees of polymerization were used. Each sample was dissolved in water at 60°C. and precipitated in the form of alginic acid by adding excess dilute HCl to the solution. The polyacid was washed repeatedly with hot water until free from Cl^- ion, and dehydrated by adding ethanol, which, in turn, was dried under reduced pressure at room temperature. Part of this polyacid was used to obtain data on the sample whose degree of ionization was zero. The remaining part of the polyacid was swollen in water and dissolved by adding excess NaOH of ca. 2N. Sodium alginate was precipitated from it by addition of ethanol, and after the alcohol had been removed by addition of ethyl ether, the material was dried under reduced pressure. The films used for the swelling experiments were cast from 3% aqueous solution of this purified polysalt on a glass plate and dried at 60°C. to constant weight. The water used in this procedure and in the subsequent measurements was prepared by making distilled water flow through monobeds of Amberlite IR-120 and IRA-400.

The degree of polymerization DP (viscosity-average) of the polyelectrolyte was evaluated from its intrinsic viscosity in 1NNaCl solution at 25°C., using KAGAWA-TAKAHASHI's equation.[4] The $\overline{DP}$ values of 830 and 460 were obtained for the two alginate samples studied.

Equilibrium swelling volumes of the gel were determined gravimetrically using the procedure described elsewhere.[5]

The salts studied were NaCl, KCl, K_2SO_4, K_3PO_4 and $K_4Fe(CN)_6$. These polyvalent salts having the common cation were chosen to investigate the specific action of different anions on the swelling behavior of this anionic polyelectrolyte. The DONNAN distribution of small ions was measured only for NaCl and KCl solutions, by dissolving the swollen gel in pure water and analyzing the resultant solution for Cl^- ions by chemical titration with 0.1 N $AgNO_3$.

The degrees of neutralization of the polysalts were checked by potentiometric (back) titration with 1/14 N HCl and found to be practically unity. All the measurements were carried out at 26°C.

Results and Discussion

Figure 1 shows the swelling curves in NaCl and KCl solutions for gels with different degrees of polymerization. The initial part of the curves for sodium

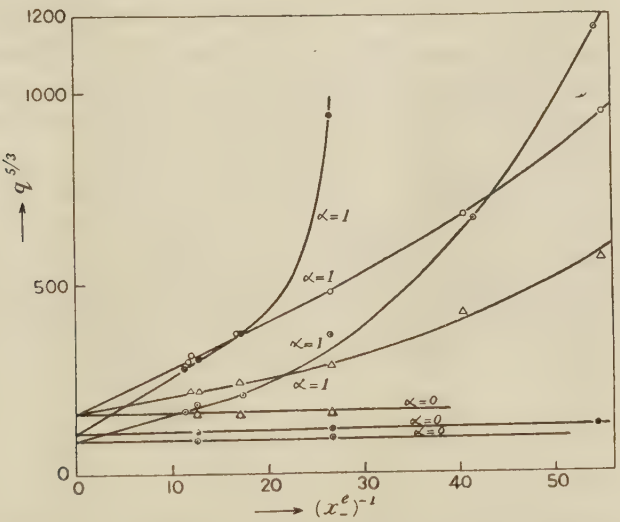

Fig. 1. Swelling curves in NaCl and KCl solutions for sodium algtnate ($\alpha=1$) and alginic acid ($\alpha=0$) with $\overline{DP}=830$ and 460. • $\overline{DP}=830$, ◉ $\overline{DP}=460$ in NaCl; ○ $\overline{DP}=830$, △ $\overline{DP}=460$ in KCl.

alginates ($\alpha=1$) is practically linear, in agreement with Eq. (I–14), and is followed by an upward curvature. This same trend was observed by VERMAAS and HERMANS[1] in their study on sodium cellulose xanthate. The swelling of alginic acids ($\alpha=0$) is independent of salt concentration within the range studied. For a given salt and a given degree of polymerization, swelling curves for polysalt and polyacid have a common intercept on the ordinate axis, demonstrating that the requirement of Eq. (I–14) is fulfilled. At equal salt concentration, the degree of swelling for fully ionized alginate increases with increasing degree of polymerization, in both NaCl

and KCl solutions. It is important to notice that the curves for NaCl and KCl for a given polysalt do not coincide each other; this implies some specific difference in swelling action on sodium alginate to exist between Na^+ and K^+.

The data may be analyzed in terms of Eq. (I–14) to obtain the values of μ and Z for respective systems indicated. The values obtained are listed in Table 1. wherein the values of the slope and the intercept of each curve are also recorded. For a given degree of polymerization the chain length Z is identical for both NaCl and KCl solutions within experimental error.

Table 1. Swelling data on sodium alginate in univalent salt solutions

$\overline{DP}$	Solution	Slope	Intercept	Z	μ
830	NaCl	14	110	16	0.46
830	KCl	12	160	14	0.43
460	NaCl	7.0	90	8	0.43
460	KCl	5.2	160	6	0.40

The reason that Z increases with increasing degree of polymerization is not clear to us. The small values of Z obtained indicate that the sodium alginate gel behaves like a network of short chains. This trend has already been noticed by VERMAAS and HERMANS[1] for cellulose xanthate gels. The values of μ obtained do not give rise to special comment. The order of magnitude of these values is consistent with a value of 0.49 derived by KAGAWA and coworker[4] from osmotic pressure measurements on sodium alginates in 1 N NaCl.

Figure 2 shows the logarithm of the molar fraction of chloride ion, x_-^e, in the

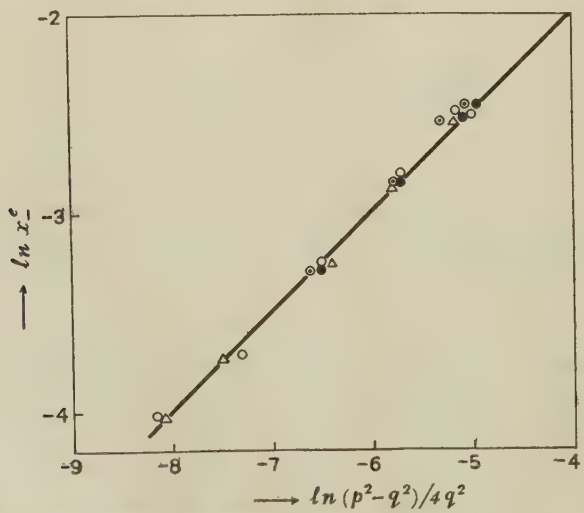

Fig. 2. Experimental verification of DONNAN equilibria. points, experimental (symbols are the same as those in Fig. 1.); solid line, drawn according to Eq.(I–11).

external solution as a function of the logarithm of $(p^2-\alpha^2)/4q^2$ for both polysalts. It is seen that points from different polysalt samples and different salt solutions fall on a single straight line which passes through the coordinate origin and has a slope of 1/2, in excellent agreement with the DONNAN equation (I–11).

Figure 3 shows the results of swelling measurements for the high molecular

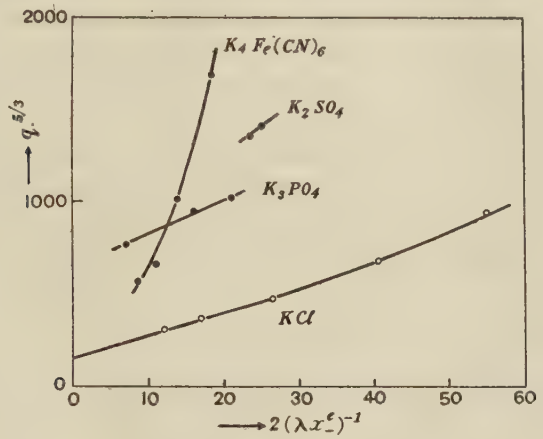

Fig. 3. Swelling curves in various salt solutions for sodium alginate with $\overline{DP}=830$.

weight sodium alginate in polyvalent salt solutions. The theory requires that all the curves should fall on a single curve when $q^{5/3}$ is plotted against the reciprocal of λx_-^e. The results in Figure 3 are entirely different from this theoretical picture, and suggest a specific lyotropic action of each polyvalent anion on sodium alginate.

Part II. Viscosity of Sodium Alginate in Aqueous Sodium Chloride

Introduction

In this part, data of a viscometric study on an alginate sample in dilute aqueous solutions containing various amounts of sodium chloride and their interpretations in terms of some current theories of linear polyelectrolytes of the coiling type are presented. The viscous behavior of alginates in aqueous solutions has been the subject of a number of investigators in colloid and in high-polymer chemistry. However, it appears that no sufficient experimental data are yet available which permit evaluation of the dimensions of the alginate molecule in a given salt solution on the basis of current theories of flexible polyelectrolyte molecules.

Experimental

Materials. The sodium alginate used was one of the two samples adopted in the swelling study described in Part I. The number of ionizable group (probably, —COONa only in the present case) per polymer molecule, Z, was determined by conductometric titration, in which a 40 ml. polysalt solution of 0.32% concentration was titrated with 1/14 N H_2SO_4 in the presence of excess NaOH.

The sample powder was dissolved in pure water at room temperature to make up a stock solution of about 0.32% concentration, which was then allowed to stand for about 1.5 hours in a water bath at 65°C., with occasional shaking. After the polymer had gone to complete dissolution, the solution was successively filtered through sintered glass filters, No. 2 and No. 3, and kept at 40°C. in a thermostatted water bath in which the viscosity measurements were to be carried. The water used as "solvent" was prepared by flowing distilled water through monobeds of ion-exchange resins, Amberlite IR—120 and IRA—400. Only freshly prepared water was used for the viscometry. All precautions taken in the preparation of the test solutions as well as in the subsequent viscosity determination were essentially the same as those described previously by FUJITA and HOMMA.[6a) 6b)] As for the more detailed account of this matter, one may refer to the excellent articles by PALS and HERMANS[7)] and by BENNINGA.[8)] The concentration of the stock solution was determined, as usual, by careful evaporation of its known volume followed by accurate weighing of the residue.

Sodium chloride, which had been purified by recrystallization from a high grade product, was used to study the effects produced by the addition of a simple electrolyte.

Viscometry. A capillary viscometer of the UBBELOHDE type (suspended meniscus)

having a flow time for water at 25°C. of 365.0 sec. was used throughout the present investigation. For a more accurate work a capillary viscometer having a much longer flow time for solvent would have been desirable. The UBBELOHDE type viscometer was employed because of its advantages over the usual OSTWALD type, as evidenced by PALS and HERMANS.[7] All measurements were carried out in a constant temperature water-bath controlled to within 0.01°C. of 40°C. This rather high temperature was employed to keep the solutions from gelation which might have occurred at lower temperatures. The efflux time was measured with a stopwatch reading to an accuracy of 0.1 sec. The kinetic energy correction was negligible in all cases studied within the accuracy of the present work. The drainage- and other minor corrections were assumed to be ignored. The reservoir of the viscometer had been designed to hold approximately 40 ml. of liquid without disturbing the suspended level. This made it possible to perform successive dilutions within the viscometer Figure 4 shows a schematic view of the viscometer used. When the capacity of the reservoir was reached, a portion of the solution was taken out of the viscometer, and after the inside of the viscometer had been completely cleaned, it was introduced in and the measurements were continued down to lower concentrations. In this manner, an entire concentration range to be investigated was covered with a single master solution. As FUJITA, MITSUHASHI and HOMMA[9] pointed out, it was found essential to effect complete mixing of the solution in the reservoir of the viscometer, in order to obtain satisfactory data. This was done by flowing dry air into the viscometer from one of its arms using a device similar to that described previously.[9] The correction for shear-rate effects was ignored, although there is no doubt that the viscosity behavior of such highly viscous solutions as were studied here should pronouncedly be affected by the velocity gradient of capillary flow.

Fig. 4. The UBBELOHEE type viscometer used.

Dilution procedure. PALS and HERMANS[7] have shown on sodium chloride solutions of sodium carboxymethyl cellulose and of sodium pectinate that if a given aqueous solution of a polyelectrolyte is diluted with a simple salt solution in such a way that the total ionic strength of the solution is kept constant or nearly constant, the resulting reduced viscosity (η_{sp}/C) vs. polymer concentration (C) curve becomes linear over the concentration range covered in such a dilution process. If no counterion fixation to the polyion is present, the total ionic strength of the solution

x_o should be given by

$$x_o = x + 10rC, \qquad \text{(II–1)}$$

where x is the ionic strength of the simple salt added in moles per liter, r is the equivalents of fixed charges per unit gram of polysalt, and C is the polymer concentration in grams of solute per 100 ml. solution. PALS and HERMANS demonstrated on sodium salts of carboxymethyl cellulose that when the stoichiometric value obtained from conductometric titration was substituted for r in Eq. (II–1), the experimental viscosity plots became linear over the entire ranges of C and x_o they studied. This was later confirmed, though not directly, by FUJITA and HOMMA[8a] for a sample of sodium carboxymethyl cellulose. On the other hand, TERAYAMA and WALL[10] and also INAGAKI and his associates,[11] revealed on potassium polyacrylate and sodium carboxymethyl cellulose, respectively, that the r value needed to straighten out the viscosity plot when a given polyectrolyte solution is diluted in accordance with Eq. (II–1) should in general, be much lower than that determined stoichiometrically. The data of FUJITA, MITSUHASHI and HOMMA[9] on a high molecular weight salt of polyacrylic acid also support the latter view. It seemed of considerable interest to ascertain which of these views is valid for the sodium alginate sample given for the present study.

As TERAYAMA and WALL[10] have shown, the finding of an appropriate value of r to obtain a linear isoionic viscosity plot involves a trial and error procedure which requires a great amount of work to carry through. For this reason, we here assign to r the value obtained stoichiometrically from the conductometric titration and examine if the resulting viscosity data conform to linear plots over the ranges of C ane x_o with which the present study is concerned. Actually, a value of 0.005 equivalent/g. was adopted for the sake of simplicity, in place of 0.0049 obtained experimentally. This practically involves one ionizable sodium carboxylate group in each monomeric unit of the sodium alginate molecule, i. e., the complete neutralization of the polyacid; see also OGURO's data.[12]

Results

The viscosity-average degree of polymerization was re-evaluated from more accurate intrinsic viscosity determination than that made in Part I; a value of 450 was obtained.* This gives for the viscosity-average molecular weight of the completely substituted sodium alginate a value of 8.9×10^4.

Figure 5 shows the conductometric titration data obtained, which present the type characteristic of the titration of a salt of a weak polymeric acid with a strong acid solution in the presence of the excess of a strong alkali. From the curve

* A value of 460 was obtained previously for this same alginate, but the difference from the value reported here is a matter of no practical importance.

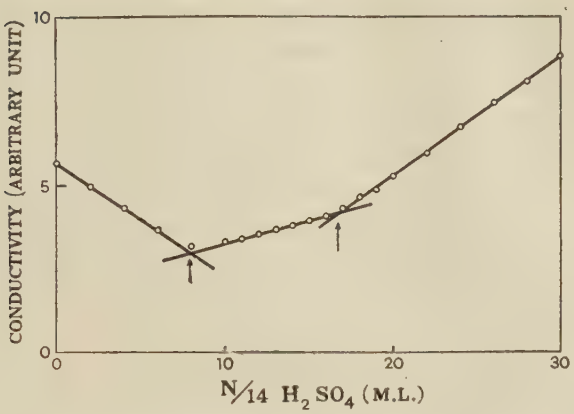

Fig. 5. Conductometric titration data for the sodium alginate studied.

shown the degree of neutralization was calculated to be 0.97, which, in turn, gives for Z, the number of carboxylate groups on the polymer chain, a value of 440.

Figure 6 presents graphically the viscosity data obtained, wherein the reduced

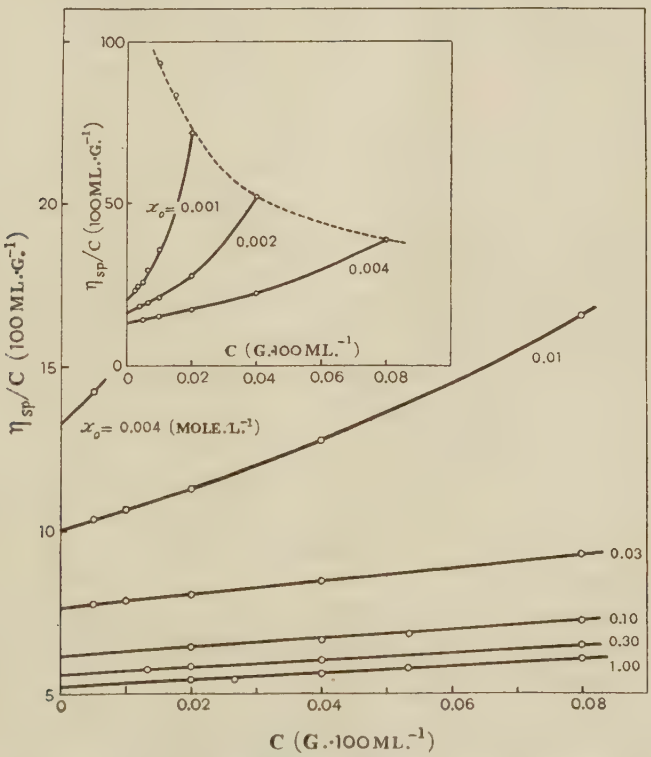

Fig. 6. Reduced viscosity curves for sodium alginate at 40°C. in NaCl solutions: x_0 denotes the total ionic strength of the solution calculated using Eq. (II-1) with r determined stoichiometrically.

viscosity η_{sp}/C is plotted against the polymer concentration C with x_o calculated from Eq. (II–1) with $r=0.005$ equivalent/g. as parameter. The solid lines represent reduced viscosities for different values of x_o, and the dashed line gives the reduced viscosity curve in pure water solutions. The curve in pure water is of the type which has recently been confirmed with various linear polyeletrolytes of moderately high molecular weights. In this work, no measurement was attempted in pure water solutions down to as low a concentration as that at which the curve passes through a sharp maximum, as recently noted for typical polyelectrolytes such as sodium carboxymethyl cellulose[6a),13)] and sodium polymethacrylate.[14),15)]

It is observed from Figure 6 that, except at relatively high ionic strengths, the viscosity plots for solutions containing added NaCl are not linear but show a distinct upward curvature over the concentration range indicated. The curvature is seen to increase sharply with decreasing x_o. Thus, if a linear viscosity plot should be obtained when the "true" total ionic strength of the solution is kept constant for a series of solutions diluted in accordance with Eq. (II–1), the curved viscosity plots obtained for sodium alginate would merely be locii of the points on which the "apparent" total ionic strength as calculated from Eq. (II–1) with the stoichiometric

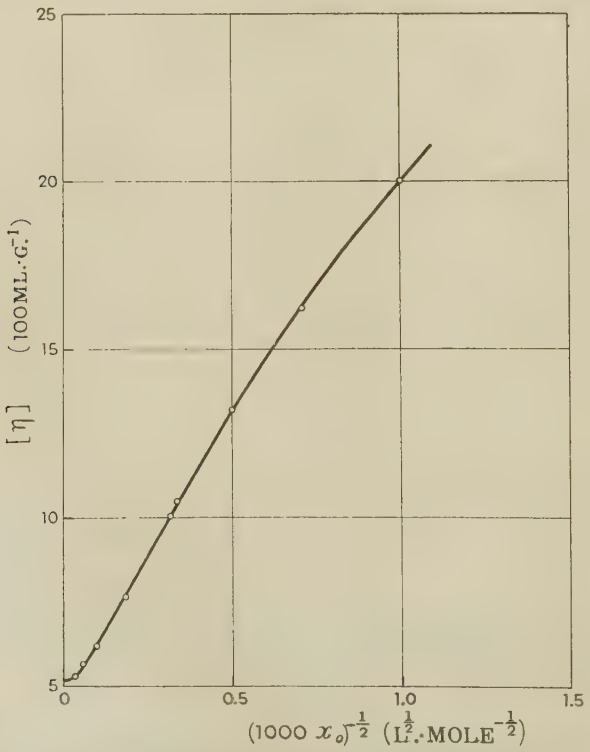

Fig. 7. Intrinsic viscosity plotted against $(1000x_o)^{-1/2}$.

r is the same. We might call such a locus on the viscosity diagram an "apparent" isoionic dilution curve. It is obvious, however, that the reduced viscosities extrapolated from a family of such apparent isoionic dilution curves to zero polymer concentration yield intrinsic viscosities for the corresponding values of x_0, although there is some difficulty in the extrapolation of such curves because of their nonlinearity. In Figure 7 the intrinsic viscosities $[\eta]$ obtained in this manner are plotted against the reciprocal square root of x_0, in accordance with Pals and Hermans. From the graph the $[\eta]$ value at the limit of infinite ionic strength is extrapolated to be 5.1_6 (100 ml./g.). This will be hereafter designated by $[\eta]_\infty$.

Discussion

The viscosity data described above will now be analyzed in terms of the theory of HERMANS and OVERBEEK[16] and that of FLORY[17] to evaluate molecular dimensions of this polyelectrolyte in solutions of a simple electrolyte. In recent years, numerous theories have been presented concerning the expansion behavior of a flexible polyelectrolyte molecule in aqueous solutions containing added simple electrolytes, but, so far as the present authors are aware, none of them is yet tested on the viscous behavior of alginates in simple salt solutions. In what follows, we shall not go into the extensive tests of all existing theories, but confine ourselves only to the two typical theories mentioned above.

Application of the theory of HERMANS and OVERBEEK. Before proceeding to apply the theory of HERMANS and OVERBEEK (the H–O theory) to the present data, we consider the limiting behavior of a polyelectrolyte molecule in solution of infinitely high ionic strength. With increasing concentration of the added simple electrolyte, the fixed charge sites on the polyion are progressively surrounded by dense counterion atmospheres. As a result the repulsive Coulombic forces between them are correspondingly diminished. At the limit of infinite ionic strength the polyelectrolytic character of the polymer thus completely suppressed, and the molecule is supposed to behave like a neutral polymer in organic (non-polar) solvents. It has been thoroughly confirmed that the mean square end-to-end distance of a non-ionic flexible linear polymer molecule in a non-polar solvent is given with a remarkable accuracy by the FLORY-FOX equation[18]:

$$\overline{h^2}=\left(\frac{[\eta]M}{\Phi}\right)^{2/3}, \qquad \text{(II–2)}$$

where M is the molecular weight of the polymer, $[\eta]$ is the intrinisic viscosity in the given solvent at a given temperature, and Φ is a universal constant of the order of 2.1×10^{21} for polymers of the vinyl type. If the effective bond-length b defined by $\overline{h^2}=Pb^2$ is used, Eq. (II–2) may be written

$$b=\left(\frac{[\eta]m}{\Phi}\right)^{1/3}P^{-1/6}, \qquad \text{(II–3)}$$

where P is the degree of polymerization of the polymer and m is the molecular weight of its monomeric unit. If a given polyelectrolyte behaves like a neutral polymer in organic solvents at the limit of infinite ionic strength as has been mentioned above, we may use Eq. (II—2) or (II—3) to evaluate the molecular parameter $\overline{h^2}$ or b at such a limit by inserting for $[\eta]$ the value $[\eta]_\infty$ derived experimentally in the manner described previously. Thus, substitution of the values for our alginate sample, i. e., $P=450$, $m=198$ and $[\eta]_\infty=5.1_6$ (100 ml./g.), provides*

$$(\overline{h^2})^{1/2}=610 \text{ Å.},$$
$$b=29 \text{ Å.} \qquad \text{(II—4)}$$

The fully extended length of the molecule, L, is the product of P times the length of the monomeric unit (5.15 Å.), giving

$$L=2330 \text{ Å.} \qquad \text{(II—5)}$$

The b value obtained leads to a value of 159 Å. for the length of a statistical segment in KUHN's sense, which is quite reasonable for a cellulosic polymer such as the sodium alginate herein concerned[19].

Based on the theory of HERMANS and OVERBEEK cited above, PALS and HERMANS[7] derived a method which permits evaluation of the effective bond-length b of a flexible polyelectrolyte in a sample salt solution at infinite ionic strength from data of $[\eta]$ as a function of $(x_0)^{-1/2}$, where x_0 is the ionic strength of the added salt. Their final equation is written

$$b^{3/2}=568\ Z P^{-3/4} B^{-1} N_A^{-1/2}, \qquad \text{(II—6)}$$

wheae Z is the number of ionizable groups per polysalt, N_A is Avogadro's number, and B is a parameter related to the slope of a linear part in the $[\eta]$ vs. $(x_0)^{-1/2}$ curve. As for the details of the derivation of this equation and the exact definition of B one should refer to the original paper of PALS and HERMANS. Introduction of the values obtained in the experiments reported in the previous paper yields for b

$$b=59\text{Å}. \qquad \text{(II—7)}$$

This is as large as about twice the value obtained above from $[\eta]_\infty$, and leads to an unreasonably high value for the length of a statistical segment (670 Å). The same discrepancy concerning the effective bond-length of a polyelectrolyte has already been noted by FUJITA, MITSUHASHI and HOMMA[8] for a sodium polyacrylate sample of very high molecular weight, and later by INAGAKI, SAKURAI and ODA[11] for sodium carboxymethyl cellulose. INAGAKI et al. attributed this discrepancy to a binding (an association as they termed) of counterions to the oppositely charged polyion.

* It is reported that Φ for polymers having stiff chains should be smaller than that for flexible polymers of the vinyl type. However, because of the lack of appropriate data for alginates, we here use the value for vinyl polymers.

Such binding apparently reduces the stoichiometric charge number Z to its certain fraction Z^*. They determined Z^* in such a manner that Eq. (II—6) is satisfied with the b value calculated from the FLORY-FOX equation as illustrated above, and termed Z^* thus evaluated the "effective" charge number. Although it is difficult to decide without accumulating much more experimental and theoretical informations whether this redution of the stoichiometric charge is due to a chemical binding of the counterion to the polyion or a physical one of the electrostatic nature, there is no doubt that the introduction of the effective charge is a useful modification of the HERMANS-OVERBEEK theory to account for the quantitative discrepancy from experiment. It should be noted here that the concept of "counterion-binding" is not a new one but has already been discussed by various authors, notably by SCHNEIDER and DOTY[20] and by FLORY and OSTERHELD[21], from viscometric, osmotic, and potentiometric titration data on well-established polyelectrolytes. RICE and HARRIS[22),23)] worked out a theory of randomly kinked polyelectrolyte molecules by taking the counterion-binding effect into account. We shall not, however, go into the details of this point in the present article. The ratio of Z^* to Z for the present alginate sample is found to be 0.358; this indicates that the polyion behaves viscometrically as if only 35% of its ionizable groups were neutralized. A value of 0.40 was obtained for this ratio by INAGAKI et al.[11] for a sample of sodium carboxymethyl cellulose (degree of etherification was about 0.7). If this apparent

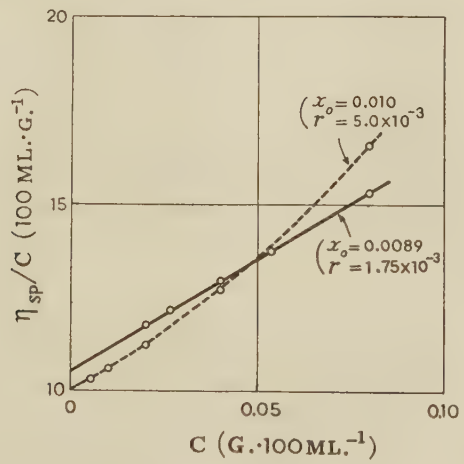

Fig. 8. Reduced viscosity curves for sodium alginate at 40°C.: solid line, for solutions diluted in accordance with Eq. (II-1) with r corrected for counterion binding. dashed line, for solutions diluted in accordance with Eq. (II-1) with uncorrected r.

reduction of the stoichiometric charge number is maintained also in solutions of dilute but finite concentrations, it is expected that when a given aqueous solution of a polyelectrolyte is diluted in accordance with Eq. (II—1) now with a new value

of r calculated in terms of the effective charge Z^*, the resulting reduced viscosity plot will become linear in the range of dilute enough concentrations. A test of this prediction was made in solutions having an x_0 value of 0.0089 mole./l., and the viscosity data obtained are plotted in Figure 8 by a solid line. The linearity of the plot is obvious, when compared it with the dashed line therein indicated, which is the data for solutions whose apparent ionic strength (calculated with the stoichiometric r) was 0.01 mole./l. and has been reproduced from Figure 6.

Once the values of $[\eta]_\infty$ and B have been obtained experimentally, we can predict the entire course of $[\eta]$ vs. $(x_0)^{-1/2}$ from theory of HERMANS and OVERBEEK. The calculated curve is shown in Figure 9 by a dashed line and compared therein

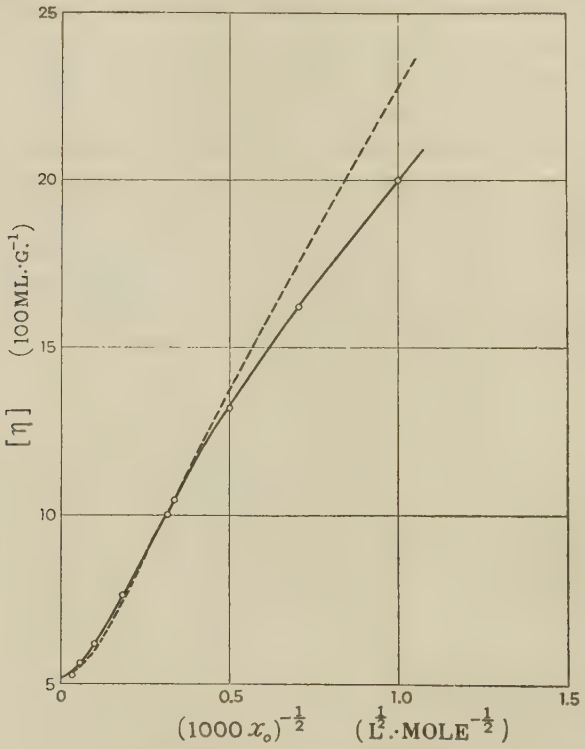

Fig. 9. Solid line, experimental. Dashed line, calculated using the theory of HERMANS and OVERBEEK.

with the experimental values reproduced from Figure 7. Remarkably good agreement between theory and experiment is seen in the region of high ionic strength; of particular interest is the excellent fit in the region where the observed data begin to level off with increasing x_0. The increasing deviation of the theory with the actual values at low ionic strengths is of the type which has already been noted by PALS and HERMANS in their study on sodium carboxymethyl cellulose.

Application of the theory of FLORY. Based on the DONNAN equilibrium theory to calculate the osmotic contribution of the mobile ions to the free energy of expansion of the polyelectrolyte molecule, FLORY[17] derived the relation:

$$\alpha^5-\alpha^3=A+2C_{\mathrm{I}}i^2M^{1/2}/S, \qquad \text{(II—8)}$$

where α is the expansion ratio defined by

$$\alpha^3=[\eta]/[\eta]_\Theta \qquad \text{(II—9)}$$

and C_{I} is[20]

$$C_{\mathrm{I}}=3.56\times10^{-22}\left(\frac{\overline{r_0^2}}{M}\right)^{-3/2}m^{-2}, \qquad \text{(II—10)}$$

M being the molecular weight of the polymer, m the moleculer weight of its monomeric unit, and i the degree of ionization. In Eq. (II—9), $[\eta]$ is the intrinsic viscosity in a given salt solution of ionic strength x_0, and $[\eta]_\Theta$ is the intrinsic viscosity in a solution in which the second virial coefficient in osmotic expansion becomes zero. The quantity $\overline{r_0^2}$ in Eq. (II—10) represents the mean square end-to-end distance exhibited by the molecule in the condition corresponding to $[\eta]_\Theta$. The first term A in the right-hand side of Eq. (II—8) is the well-known non-ionic contribution and the second is the first of a series of terms making up the ionic contribution.

In applying Eq. (II—8) to experimental data, it is first necessary to evaluate $[\eta]_\Theta$. Since, however, its exact evaluation requires a great amount of experimental work, we here assume, in accodance with the finding of SCHNEIDER and DOTY[20] in sodium carboxymethyl cellulose solutions, that $[\eta]_\Theta$ is set equal to $[\eta]_\infty$; this means to assume that the second virial coefficient vanishes at the limit of infinite ionic strength. This is also equivalent to assuming that the non-ionic contribution to the expansion of the molecule, which is actually represented by the first term in Eq. (II—8) is negligible compared with the ionic contribution. Under this condition, $\overline{r_0^2}$ should amount to $\overline{h_0^2}$ evaluated above in terms of the FLORY-FOX equation for uncharged polymers.

The comparison between Eq. (II—8) and the observed data is made in Figure 10, where $\alpha^5-\alpha^3$ derived from the data shown in Figure 7 is plotted against the reciprocal ionic strengh x_0^{-1}. In contrast to the sodium salts of a polyacrylic acid investigated by FLORY and OSTERHELD,[21] our plot shows a linearity only in a very limited range near the coordinate origin. The slope of this linear part is 1.63×10^{-2}, whereas the value predicted from Eq. (II—8) with $i=1.00$ is 0.640; thus, the theoretical slope is about 40 times that of the experimentally derived line. Similar enormous differences between theory and experiment have recently been found for various polyelectrolytes[20)21)24)]. FLORY and OSTERHELD[21] observed on a polyacrylic acid neutralized to various degrees that discrepancy increased with increasing degree of neutralization, and suggested that this is due to electrostatic "binding" of counterions

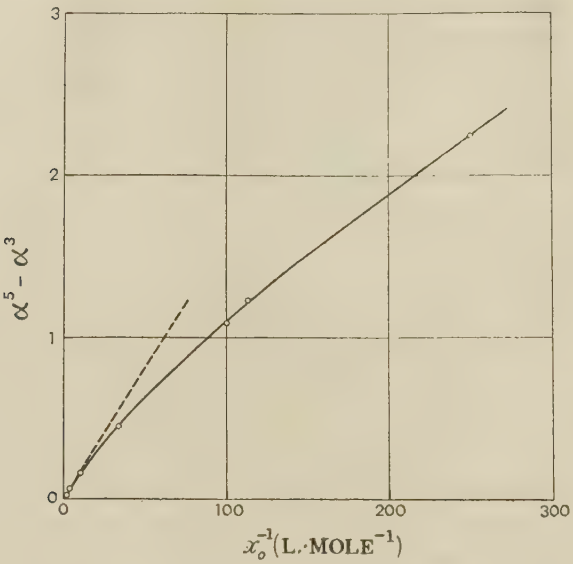

Fig. 10. Test of the FLORY equation.

by the relatively high potential in the vicinity of the polymeric ion. This is essentially the same idea as that which we have reached above from the consideration of the effective bond-length in terms of the theory of HERMANS and OVERBEEK. Along the same line of thought it is possible to introduce an "effective" degree of ionization i^* so that the slope predicted from Eq. (II—8) agrees with the experimental value. By doing so, we obtain for i^* a value of 0.16, which is about one-half the effective degree of neutralization as deduced above in terms of the ratio of Z^* to Z. Although we have no definite theoretical foundation to decide which is more real, it appears, in our opinion, that the value from the FLORY theory is less acceptable. It is apparent that much more work, both experimental and theoretical, need be done before we can arrive at the elucidation of the real reason for the discrepancies observed above concerning quantitative interpretation of the viscous behavior of sodium alginate in aqueous NaCl in terms of the current polyelectrolyte theories.

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A Preliminary Report on the Fin Organ of a Soleoid Fish, *Pardachirus pavoninus* (Lacépède)

By

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With 3 Text-figures

(Received Dec. 25, 1956)

Pardachirus pavoninus is a dainty and strikingly-marked sole and is one of the rarest fish found in the Japanese waters, although it is rather widely distributed in some other regions, particularly in the tropical waters of the Indo-Western Pacific. As already quite well remarked, this sole is clearly distinguished from other related dextral soles in having so characteristic a coloration that in formalin the body and fins on the eyed side are colored blackish brown, and densely specked entirely with roundish lighter patches, each of which is bordered by a dark line and generally spotted with a blackish speck in the center (Fig. 1).

The sole is also remarkable in having a series of numerous small openings running along the outer margin of the body. In 1862 Günther pointed out such openings as an important diagnostic feature of his genus *Pardachirus*. Since then, the openings have been well remarked, so far as my knowledge is concerned, by other ichthyologists in their studies of this group, but the accurate anatomical feature of this peculiar apparatus has not yet been reported. The present paper gives a result of the morphological study of the organ concerning the opening.

The author is indebted to Prof. Kiyomatsu Matsubara of our department, Prof. Mitsuo Sato of Biological Laboratory, Faculty of Literature and Science, Hirozaki University, and Dr. Paul Chabanaud of Muséum National d'Histoire Naturelle in Paris, for their pertinent criticisms and helpful suggestions. Thanks are due to Mr. Toru Takai of Shimonoseki Fisheries College who supplied the author with a valuable specimen for the use of the present study.

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Material and Method

Two specimens of this sole are used in this study. One (No. 25091, 189 mm in standard length) was taken from Miya, Aichi Pref., on December 20, 1954. The other (No. 25546, 187 mm) was obtained from Okinawa, one of the Riu Kiu Islands

about fifteen years ago. They have been preserved in ten-percent formalin solution. The general characteristics of the organ are studied in a complete set of serial sections at 20μ thickness of the organ cut off from the dorsal side of the body of the latter specimen. All sections are stained with HEIDENHAIN's azon.

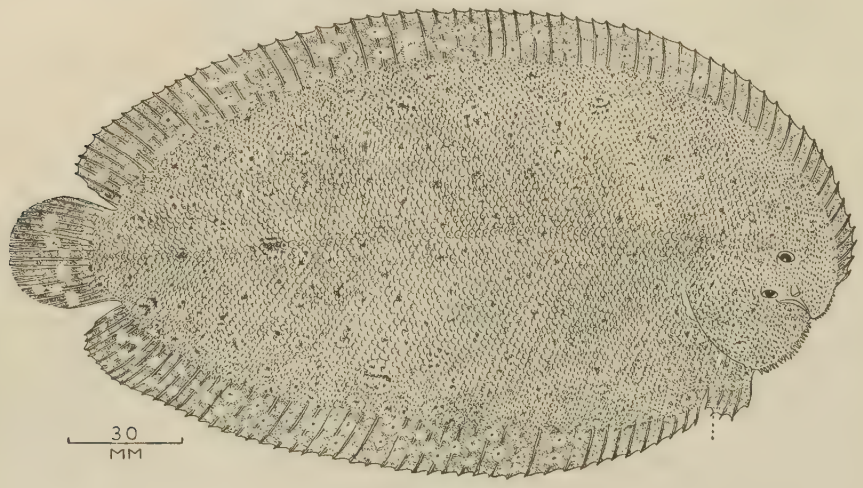

Fig. 1. *Pardachirus pavoninus* (LACÉPÈDE). No. 25091, 189 mm in standard length. Drawn by the present author.

Gross and Microscopic Anatomy

Roundish or slit-like pores are about 0.5 mm in diameter, opening on both sides of the body near the base of each soft ray of the dorsal, anal and ventral fins except for one or two rays located near the ends of such fins (Fig. 2B). The pore is found to be an opening of a small sac newly alluded to herein as the fin organ, the distal portion of which is firmly attached to the fin ray and the basal portion is kept between the inclined muscles of the fins aforementioned (Fig. 2 A). The anterior edge of the basal portion as well as the posterior edge of the distal half of the organ are kept with the adipose tissue. Each organ is very soft and elastic, and strikingly varies both in size and form according to its position and at every undulating movement of the fin. When the soft ray related with the organ is raised the organ takes its normal form. It is generally bottle-like in shape, attaining 16 mm in length and 4 mm in diameter on the middle portion of the body, but the organ located near the anteriormost portion of the dorsal fin is onion-like in shape, measuring 6 mm in length and 2.5 mm in diameter. When the soft ray is depressed posteriorly, the distal portion of the organ bends backward.

An examination of tissue section of the organ reveals that the organ is entirely

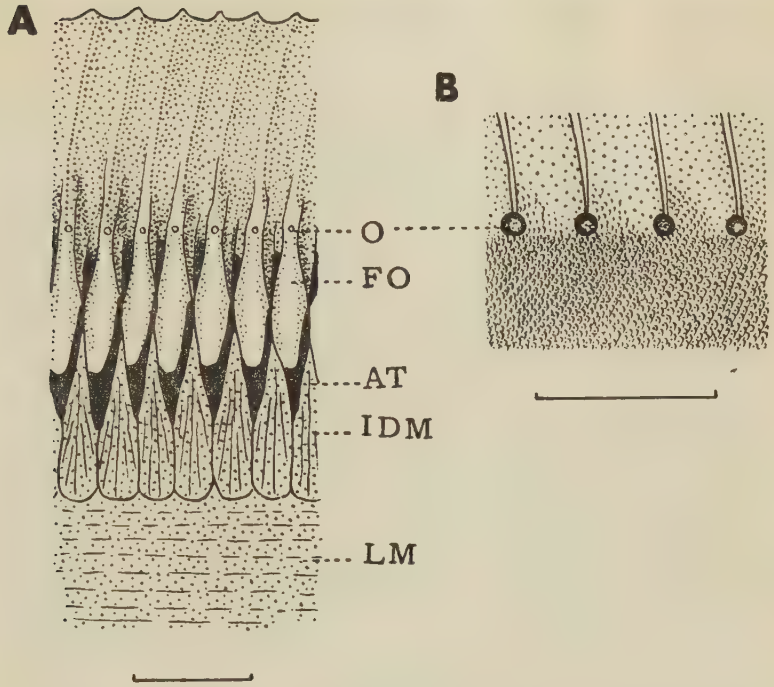

Fig. 2. Fin organ along the dorsal margin of the body in *Pardachirus pavoninus*. **A.** anatomical structures of fin organ and its neighbouring tissues. **B.** enlarged view of opening of fin organ. AT, adipose tissue; FO, fin organ; IDM, inclined dorsal muscle; LM, lateral muscle; O, opening. The scales each indicates 10 mm. Drawn by the present author.

enclosed by the fibrous connective tissue (Fig. 3). The adipose tissue keeping the organ is completely filled with small round adipose cells having an orange or orange yellow cytoplasma. A septum strikingly stained with blue is placed between the inclined dorsal muscle and the adipose tissue or the organ. About ten folds of the tissue run longitudinally along the inner surface of the organ from the base to the distal end of the organ. Each fold is formed by a cluster of large polygonal cells with red-stained nuclei which are ovoid or elliptical in shape. The cytoplasma of the cells is colorless or reddish blue. Some cells attain a size measuring 168 by 36 μ or more in their cross section, and 168 by 72 μ in their longitudinal section.

Discussion

In soleoid fish, generally, inclined muscles of dorsal, anal and ventral fins are dense in structure and rod-like in shape, running vertically in a series along the

marginal region of the body from the distal part of the lateral muscle to the bases of the fin rays, and the adipose tissue is regularly developed between them. In *Pardachirus pavoninus*, however, the inclined muscles are pyramid-like in shape, apparently separated each other at their distal portions. This modification of the muscle may presumably be caused by the existence of the fin organ, which is believed to be a cutaneous sac derived from the fin membrane.

In this fish the fin organ is symmetrically developed on both sides of the body, whereas conspicuous bilateral asymmetry is shown in various parts of the body. This fact suggests that the organ appears to take charge of a peculiar function while the fish is alive. In view of the histological structure of the organ, the polygonal cells found in the folds of it are similar to those of the axillary gland of the Mexican catfish and those of glandular triangle of the zebrafish observed by HALSTEAD and his co-workers (1953.1955).

The author can hardly defined the nature of the fin organ until biochemical studies have been made of some fresh specimens, but, taking all these things into consideration, can safely presume that the organ secretes some fluid or venom from it to the exterior of the body when it is transformed by the undulating movement of the fin.

Summary

Fin organ, which is a new term herein introduced, of a sole *Pardachirus pavoninus* is described. The organ is located near the base on each side of each soft ray of dorsal, anal and ventral fins, and is open to the exterior by a small pore. The gross and microscopic anatomy of the organ reveals that it presumably takes charge of some function as either a secretory gland or a venom apparatus.

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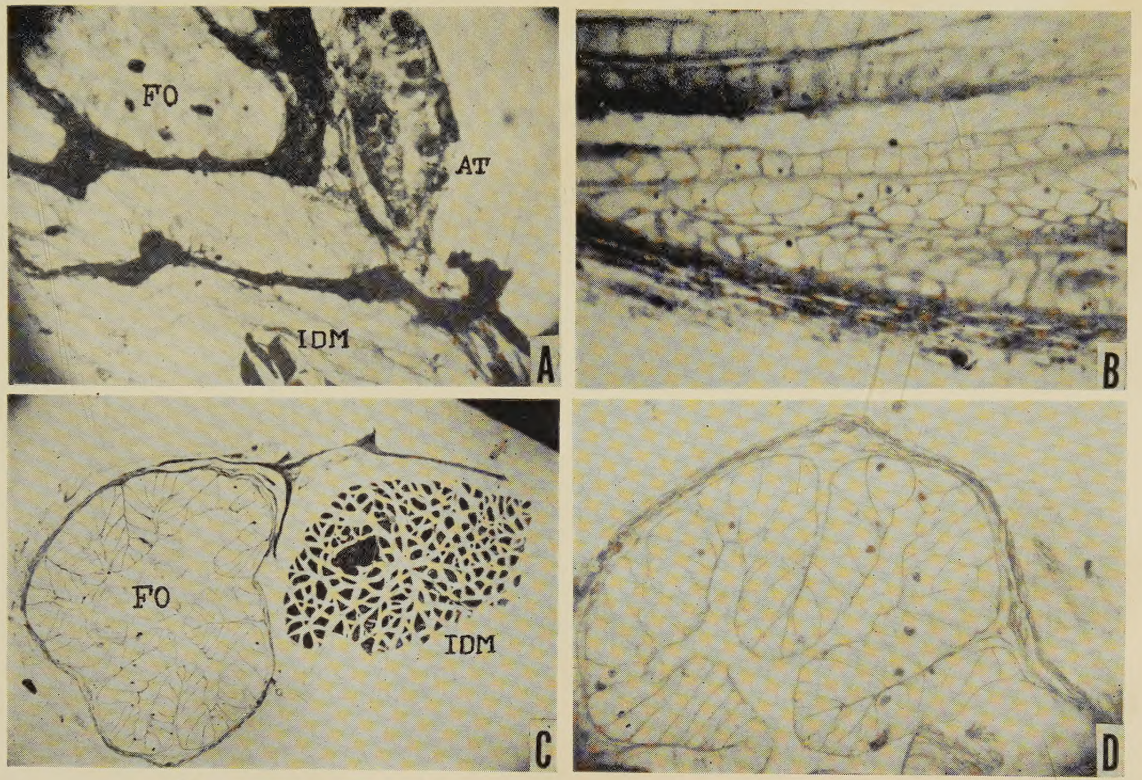

Fig. 3. Photomicrographs of the fin organ of *Pardachirus pavoninus*.
A. longitudinal section of fin organ near its basal end. ×45.
B. longitudinal section of fin organ near its distal tip. ×55.
C. cross section of fin organ at the middle portion. ×20.
D. enlarged view of large cells in the fold of organ in **C.** ×40.
AT, adipose tissue; FO, fin organ; IDM, inclined dorsal muscle.

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